Lethality-Model for HD 1.2/1.4 Ammunition Debris Throw due to an Explosion on a Vehicle

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Abstract:

In Switzerland, the risk-based safety concept is being introduced to the military transport of ammunition and explosives (TAE) in a pragmatic way. For economic reasons and matters of urgency the focus is on the safety assessment of transportation routes selected according to priorities, although there are no standardized methodology, technical manuals/directives and comprehensive computer tools yet. Lacking risk analysis models are only being developed as far and deeply as necessary to get sensible results.
One of the last such gaps is the hazard of non-massreacting ammunition debris throw due to the explosion of a part of the ammunition or explosives load on a vehicle. A literature review showed that no such models exist. Therefore, last year, the Staff of the Chief of the Swiss Armed Forces charged Bienz, Kummer & Partner Ltd. to develop an adequate model for the calculation of the ammunition debris throw lethality from explosions on TAE-vehicles within a narrow financial and time frame.

The paper is about the model, its basis and development. Data from tests (e.g. CONEX-Containers) and accidents was collected and evaluated. Based on these results and a simple engineering approach an applicable model for calculating lethalities was developed for ammunition debris from vehicles such as trucks and railway cars. It will add a new and important tool to the arsenal of the (Swiss) TAE risk analyst.

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14. ABSTRACT
In Switzerland, the risk-based safety concept is being introduced to the military transport of ammunition and explosives (TAE) in a pragmatic way. For economic reasons and matters of urgency the focus is on the safety assessment of transportation routes selected according to priorities, although there are no standardized methodology, technical manuals/directives and comprehensive computer tools yet. Lacking risk analysis models are only being developed as far and deeply as necessary to get sensible results. One of the last such gaps is the hazard of non-massreacting ammunition debris throw due to the explosion of a part of the ammunition or explosives load on a vehicle. A literature review showed that no such models exist. Therefore, last year, the Staff of the Chief of the Swiss Armed Forces charged Bienz, Kummer & Partner Ltd. to develop an adequate model for the calculation of the ammunition debris throw lethality from explosions on TAE-vehicles within a narrow financial and time frame. The paper is about the model, its basis and development. Data from tests (e.g. CONEX-Containers) and accidents was collected and evaluated. Based on these results and a simple engineering approach an applicable model for calculating lethalities was developed for ammunition debris from vehicles such as trucks and railway cars. It will add a new and important tool to the arsenal of the (Swiss) TAE risk analyst.

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1 Introduction

1.1 Background

Switzerland has successfully applied quantitative risk analysis for assessing the safety of storage, manufacture, demilitarisation, research and development, testing etc. of ammunition and explosives in the military field for almost four decades. A couple of years ago, the implementation of the risk-based safety assessment concept began in the military transport of ammunition and explosives (TAE), too [1, 2].

After some preliminary investigations to get an overview on the general state of safety in the TAE, it was decided to proceed case by case, i.e. to assess the more urgent TAE-problems mainly based on the current state-of-the-art risk analyses know-how (gained from preliminary work) which would only be improved as far as necessary for the specific case with regard to both extent and exactness. The main arguments were that in this way, practical applications and results could be gained very soon and proportionally to the investment.

So far, one of the gaps left open by this case-by-case approach was an adequate model for the hazards of non-massreacting ammunition debris throw due to the explosion of a part of the ammunition or explosives load on a truck or railway car. Last year, the Staff of the Chief of the Swiss Armed Forces charged Bienz, Kummer & Partner Ltd. (BK&P) to develop an adequate model for the calculation of the ammunition debris throw lethality from explosions on TAE-vehicles within a narrow financial and time frame.

1.2 Course of Action and General Remarks

At first, a literature review showed that no such models exist. Thus, we had to develop our own model. Consequently we looked for data from TAE-accidents and from tests conducted by other nations; conducting our own trials to get the necessary data was out of question due to limited means.

Most of the data found was from cook-off tests, where a (external) fire heats the ammunition to the point of deflagration or even detonation. The analysis of the debris data in these tests was usually limited to the far-range in order to determine the Quantity-Distance for deterministic regulations. Our goal, however, was to develop a model for calculating the lethality over the *whole range* of the debris throw for risk analysis purposes. Furthermore, the debris data from cook-off tests with their many small events is somewhat different from the assumption of one maximum credible event which serves as the basis for a risk analysis.

From the rather scarce debris data left, it was not possible to derive a sound empirical model for the debris density distribution (DDD). Consequently, we chose a simple, engineering approach using the quantity of explosives[1] (Q_{TNT}) and the type of ammunition to be ejected as main parameters. The steps were the following:

1. Estimation of the number and type of debris pieces generated at the source of the event

2. Investigation of the distribution of these ejected debris pieces in the surroundings, leading to the DDD

3. Calculation of the lethality due to debris throw, based on the DDD, the impact properties of the debris pieces and the lethal area of a person

If no other data was available, expert judgement was used in this framework. Whenever possible, the assumptions were compared to the debris data from tests and accidents and adjusted if necessary.

Finally, the model was compared with other explosion effects in order to determine its relevance for former and future TAE risk analyses. The model developed applies only to cargo with an explosive weight from a few kg to a few thousand kg.

An additional but rare hazard is the explosion of the ejected rounds of ammunition upon impact in the surroundings. This related hazard could not be included in this lethality model because of the lacking resources.

It has to be pointed out that due to financial and time restraints, the model could only be developed as far and deeply as necessary to get sensible results.

2 Data from Literature

The data of the main tests and accidents found are summarized in Table 1. The only tests which fit this problem and have well documented debris data are the ones from the US-tests with mixed ammunition boxes in CONEX-Containers and the one test with stacked HD 1.2 ammunition boxes on a fire which was almost mass-reacting (number 9). Thus, these data served as the main references for the development of the model. The relevant reports from all these tests and accidents are included in the list of references [3-6].

[1] Q_{TNT} is based on NEW, but takes the TNT-equivalent, the casing factor, etc. into account.

Event	Purpose	Remarks
US-Tests with ammo in CONEX-Containers ~1988	Propagation, Mitigation, Debris Throw	Only 5 of 11 tests useful for TAE; Debris data from tests 1-3 ~10 kg Q_{TNT}
US-Tests with stacked ammo (cook-off) ~1996	Quantity-Distances for HD 1.2	Only 1 of 12 tests useful in this context (test 9 was almost mass-reacting); Debris data from test 9 ~15 kg Q_{TNT}
German Test with ammo on truck (cook-off) 2004	General course of action for HD 1.2 cook-off	Not really useful in this context; Debris data not well known
Accident with ammo on truck in Norway 1985	-	Not really useful in this context (fire led to cook-off); Debris data not well known

Table 1: Summary of the main tests and accidents

3 Influences on Debris Throw

3.1 Introduction

The main influences on the ammunition debris throw are the following:

a. The **explosive weight (Q_{TNT})** influences the debris mass distribution (i.e. the number of debris pieces per mass class) and the debris launch velocities. The larger Q_{TNT}, the larger the radius of destruction of the ammunition around the explosion, the larger the amount of ammunition which is ejected into the surroundings, and the higher the launch velocities.

b. The **type of non-massreacting ammunition around the explosion (acceptor)** also influences the debris mass distribution. For example, robust large calibre ammunition will usually be ejected as single large pieces, while non-robust rockets or small arms ammunition boxes will probably break-up and their pieces respectively contents are ejected as many small pieces (at least in the close-range).

c. The **geometry of the load respectively the location of the explosion** in relation to the other ammunition on the vehicle influences the horizontal and vertical launch angles. These geometrical influences could only be studied summarily for the model and will thus not be discussed in detail in this paper. It is important to note that the debris distribution was assumed to be circular.

d. Finally, the **type of ammunition or explosives which actually explodes (donor)**. If it is a mass-reacting donor, it will usually be separated from the non-massreacting ammunition around it by a small gap (between pallets). However, if the donor is a large piece of non-massreacting ammunition, it will typically be in direct contact with other ammunition of its kind (on the same pallet). This distinction is of some importance for the debris mass distribution, too. For Swiss TAE, the first case is taken as representative.

3.2 Number of Debris at the Source of the Explosion

3.2.1 Influence of Explosive Weight (Q_{TNT})

Generally, the larger Q_{TNT}, the larger the amount of ammunition which is ejected into the surroundings. However, in a TAE-configuration, the amount of Q_{TNT} as well as the number of non-massreacting ammunition surrounding it is limited. Therefore, it was assumed that the maximum number of debris pieces ejected will be reached at a Q_{TNT} of a few 1000 kg. For decreasing Q_{TNT}, the radius of destruction which determines the size of debris pieces as well as their number will be less and less until there will be only negligible ammunition debris throw for Q_{TNT} of a few 1 kg. Figure 2 is based on expert judgement.

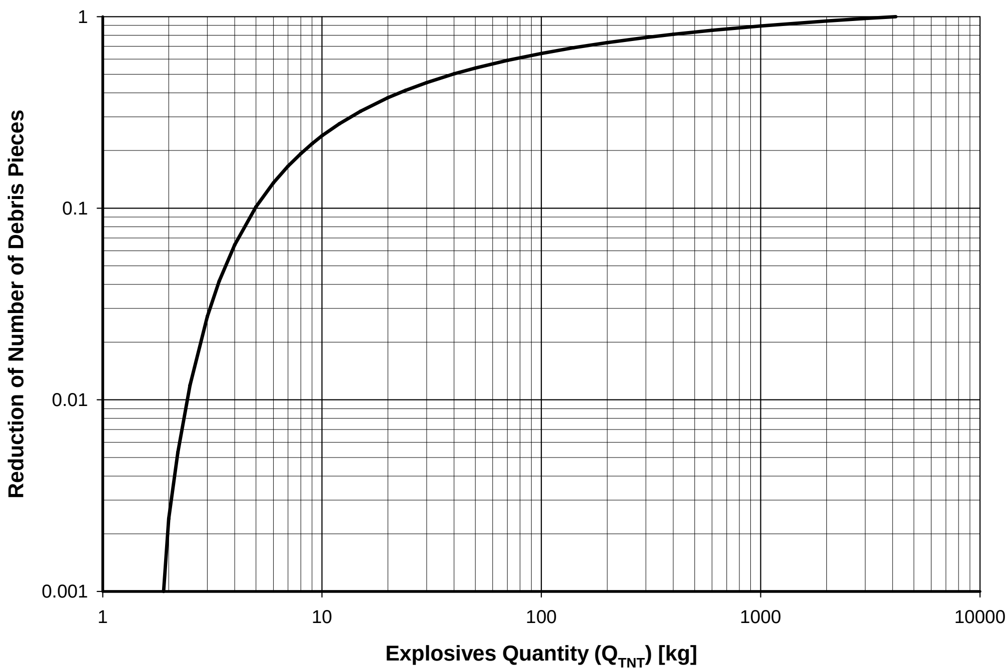

Figure 2: Reduction of the number of debris pieces with decreasing explosive weight

3.2.2 Influence of Type of Non-massreacting Ammunition Around the Explosion

In order to take account of the potential number of debris pieces, the non-massreacting ammunition was classified into six groups.

Ammo-Group	**Calibre**	**Example**
1: Small calibre	< 10 mm	Rifle
2: Medium calibre	10 - 50 mm	Airplane cannon
3: Large calibre (Lcal)	> 50 mm	Artillery
4: Lcal + propellant	> 50 mm	Mortar
5: Small grenades	-	Hand grenade
6: Rockets / Tank	-	Tank ammo

Table 3: Classification of the ammunition

Three types of ammunition debris pieces were distinguished according to the test data:

a. Small pieces of the packaging of the mass-reacting ammunition exploding (donor)
These pieces are usually very small and have a high velocity. However, they are not primary fragments, which are taken into account by another model.

b. Small pieces of the non-massreacting ammunition around the explosion (acceptor)
The boxes and their ammunition close to the explosion will get more or less shattered, also depending on their robustness. These pieces will have a medium velocity.

c. Whole boxes of the non-massreacting ammunition
The boxes farther away from the explosion will be ejected in one piece without shattering. They will have a relatively low velocity.

For all debris types, the minimal weight of a debris piece still having lethal energy (> 79 J) after a certain distance could be derived using the code TRAJ, assuming a certain starting velocity (also from back-calculation of their maximum range, see 3.3), and as a function of the explosives weight (Q_{TNT}). This is also depending on the material of the piece of ammunition or packaging. Then, knowing the weight of the box or the piece of ammunition, the maximum number of resulting hazardous debris pieces can be calculated from that minimal weight. Typically, the number of debris pieces derived in this way is in the tens for a box (without contents) close to the explosion and in the low hundreds for a box of the exploding ammunition.

Using TRAJ, it was also found that the single pieces of small arms ammunition will usually not be lethal as ammunition debris throw as defined here.

3.2.3 Matrix for the Number of Debris Pieces

All information about the influence of the quantity of explosives (Q_{TNT}) and the type of ammunition on the number of debris pieces generated by the explosion was put together in a matrix. The three types of debris pieces introduced in 3.2.2 were distinguished because they have different trajectories respectively distribution due to their different properties:

- A ratio of 70% whole box debris and 30% single debris pieces of the ammunition around the explosion was chosen. In other words, it was assumed that about 30% of the ammunition boxes and their contents are shattered (near the explosion) and about 70% of the boxes are thrown out as one piece (further away).

- Concerning the number of debris from the packaging of the exploding ammunition or explosives (donor) a reduction is included, taking into account that only the debris pieces from the outer side(s) of a box in a stack will be ejected into the surroundings.

The maximum number of debris pieces is calculated from the number of ammunition pieces per box of the representative ammunition groups. For small arms ammunition, the single pieces of ammunition were not taken into account as they were assumed to have non-lethal energy (simulations with TRAJ, see 3.2.2).

Putting it all together, it can be seen that concerning the six representative ammunition groups, roughly three types can be distinguished:

1. Non-massreacting robust large calibre ammunition produces the least ammunition debris,

2. medium calibre ammunition and small grenades produce the most ammunition debris,

3. the other groups fall in between.

3.2.4 Plausibility and Sensitivity

No sensible comparison of the debris number at the source of the explosion between this model and the data from either the CONEX or the cook-off test 9 is possible to estimate the plausibility of the model. This is due to the lacking debris data from the tests.

Regarding the sensitivity of the model, especially concerning the type of ammunition debris, the debris number is, not surprisingly, mainly influenced by the number of shattered debris pieces from boxes and pieces of ammunition around the explosion (type b) in 3.2.2).

3.3 Distribution of Debris in the Surroundings

3.3.1 Maximum Range of Debris Pieces

A first hint about the debris distribution can be gained from the maximum range (R_{max}) of the debris pieces in the tests considered for this model.

Test	**Q_{TNT}** [kg]	**R_{max}** [m]	**Ammo-group/ Debris-type**	**Donor M / N**	**Remarks**
CONEX 1-3	10	115	1 + 5	M-Donor, separated	In Container
CONEX 10	227	335	Whole Box	M-Donor, separated	In Container
Cook-off N	1.5	350	Other Debris	N-Donor, in N-Ammo	Average Q
Cook-off N	1.5	300	4	N-Donor, in N-Ammo	Average Q
German Test	1.5	310	NA	N-Donor, in N-Ammo	Possibly Fragments
Cook-off M	15	460	4, other	N-Donor, in N-Ammo	Test 9

Table 4: Maximum range of debris pieces as a function of explosives weight (Q_{TNT}) (Numbers in column Ammo-group refer to Table 3)

It seems that the maximum debris range is influenced by the type of the ammunition which explodes respectively its configuration (see 3.1 d). The cook-off test 9 showed a significantly larger range than the CONEX tests for about the same Q_{TNT}. While the effect of the container in the CONEX tests is not known, it seems that the gap between the source of the explosion and the non-massreacting ammunition around it reduced the maximum range.

3.3.2 Calculation of Debris Trajectories with TRAJ

Further knowledge about the debris distribution can be gained from the calculations of the debris trajectories with the code TRAJ, distinguishing the three types of debris (see 3.2.2). The results can be summarized as follows (taking NATO's 79-J-lethality-criterion into account):

a. Small pieces of the packaging of the mass-reacting ammunition exploding (donor)
These fast but small pieces are usually only hazardous if on a more or less horizontal trajectory. Their starting velocity is lower than for primary fragments.

b. More or less small pieces of the non-massreacting ammunition around the explosion
Their starting velocity could, in some cases, be estimated from their maximum range (see above). The smaller of these debris pieces, such as small calibre ammunition pieces, will usually not be hazardous in the context of this model.

c. Whole boxes of the non-massreacting ammunition

Their starting velocity could, in some cases, be estimated from their maximum range (see above). Due to their weight, these debris pieces are hazardous whatever their trajectory.

3.3.3 Debris-Number-Density Distribution

Assuming that the shape of the debris-number-density distribution (DNDD) for ammunition debris throw is similar to the one for other such debris throw as e.g. for vehicle debris throw [7], a general DNDD-shape was derived.

For each ammunition group, the DNDD for each of the three debris types was calculated as a function of the quantity of explosives (Q_{TNT}), so that the corresponding number of debris pieces from the matrix in 3.2 was distributed according to the general DNDD-shape and the maximum range.

3.3.4 Plausibility and Sensitivity

As the comparison between the DNDD of the model and those from the tests shows good agreement (Figure 5), the models seems to give plausible results. Comparison with the CONEX tests is easier, even though it is only possible for the small grenades. It shows that the ratio of 70% whole box debris and 30% single debris pieces of the ammunition around the explosion is reasonable. Comparison with cook-off test no. 9 is difficult, primarily because an unknown number of non-lethal debris pieces would have to be excluded.

Concerning sensitivity, the differentiation of the explosives weight (Q_{TNT}) and ammunition groups seems to work.

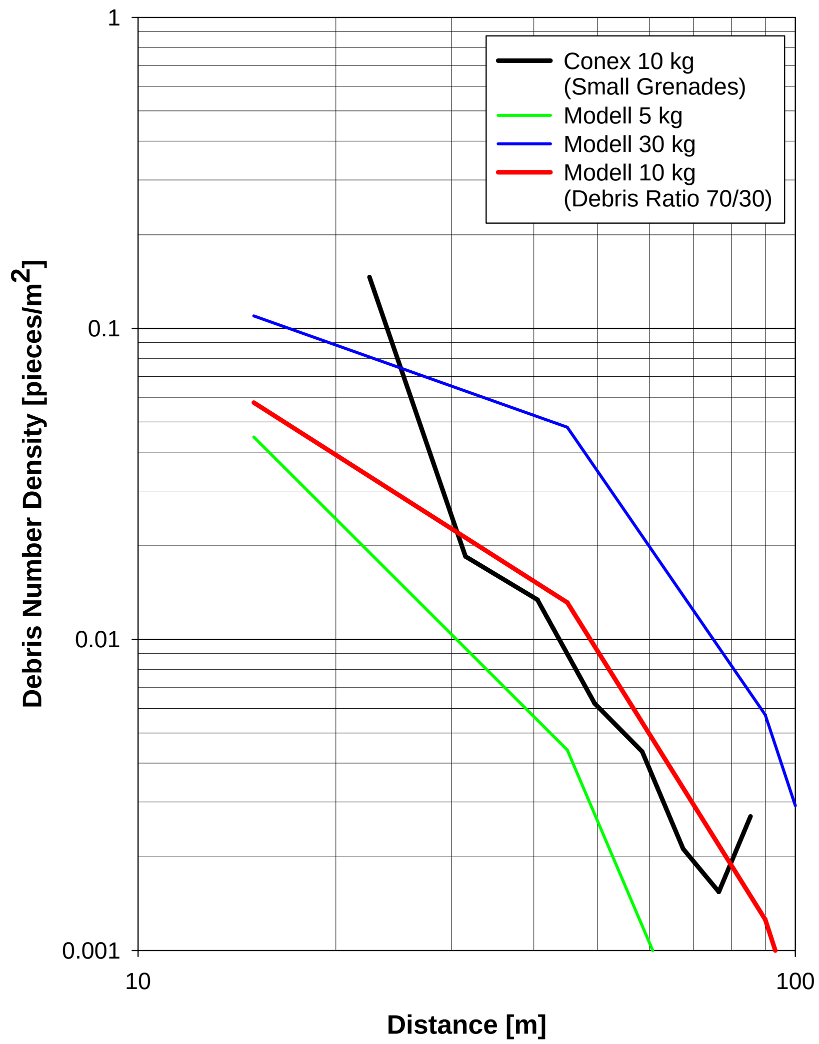

Figure 5: Comparison of Debris-Number-Density-Distributions

4 Lethality due to Debris Throw

4.1 Introduction

For risk analyses, debris densities have to be transformed into lethalities. In this study, only lethalities for people exposed on the free field were investigated. People in buildings are somewhat protected from debris throw (mainly depending on the building construction and the area of the windows). A detailed model that is able to calculate the lethalities inside buildings due to debris throw was only finished recently in Switzerland (see paper of Peter Kummer, BK&P, presented in the same session [8]).

The derivation of the lethality function for the mid- to far-field was based on the DNDD (see Figure 5 as example); however, additional parameters such as the angle of the incoming debris and the relevant body area of exposed persons needed to be known. For the close-range a different approach had to be chosen because of the mainly horizontal debris trajectories.

As a reasonable simplification we did not take the different vulnerabilities of the different body parts into account. The relevant body area was chosen to be 0.4 m^2 (only 0.2 m^2 for the small type a) debris pieces, see 3.2.2), which accounts for different body positions (standing, prone, etc.). We conservatively assumed that all debris pieces with more than NATO's 79 J criteria are lethal on that body area.

4.2 Comparison with other Explosion Effects and Relevance

The relevance of this lethality model for non-massreacting ammunition debris throw was checked by comparison with other explosion effects, for people exposed on the free-field:

- Air blast:
  For free-field exposition, air blast generates decisive lethalities in the close-range only.
  → Air blast lethalities are clearly lower than the ones of the ammunition debris for the range of explosive weights studied

- Vehicle debris throw:
  The vehicle transporting explosives will be shattered into many debris pieces for relatively large quantities of explosives only [7].
  → Vehicle debris lethalities are slightly higher than the ones of the ammunition debris for large quantities of explosives

- Fragment throw:
  Significant primary fragment throw is only generated if fragmenting shells etc. are being transported. As a new model that is able to reliably calculate the fragment throw from larger amounts of such ammunition is still under development in Switzerland, the lethalities form fragment throw and the ones of the ammunition debris are difficult to compare. (This is also the case for the comparison with the code SAFER).

- Crater debris throw:
  For TAE scenarios, crater debris will usually only be relevant for explosives weights higher than the range of relevance here.

In summary, lethalities due to non-massreacting ammunition debris throw proved to be relevant for free-field exposition, especially for explosive weights in the range from a few kg to a few hundred kg (where vehicle debris throw becomes dominant).

5 Lethality Model

5.1 Lethality as a Function of Distance, Q_{TNT} and Type of Ammunition

The type of non-massreacting ammunition around the explosion influences the number of debris pieces and therefore the lethality. Table 6 shows the debris throw potential of the six groups of ammunition investigated here:

Ammo-Group	**Debris Throw Potential**		
	large	**medium**	**small**
1: Small calibre		X	
2: Medium calibre	X		
3: Large calibre (Lcal)			X
4: Lcal + propellant		X	
5: Small grenades	X		
6: Rockets / Tank		X	

Table 6: Debris throw potential of the ammunition groups

So far, the lethalities due to ammunition debris throw were calculated for some debris densities only, as a function of the distance and the explosives weight (Q_{TNT}). Now, a simple but adequate lethality model is developed for all relevant debris densities (see Figure 7). This model calculates probit-values, which can then be converted to lethalities (see Table 8).

$$\mathbf{Pr = a + b \cdot \ln (D)}$$

Or:

$$\mathbf{D = e^{(Pr - a) / b}}$$

where Pr: Probit-value of lethality
a and b: Functions of explosives weight [kg]
D: Distance [m]
Range of explosives weight (Q_{TNT}): 1.5 – 3000 kg

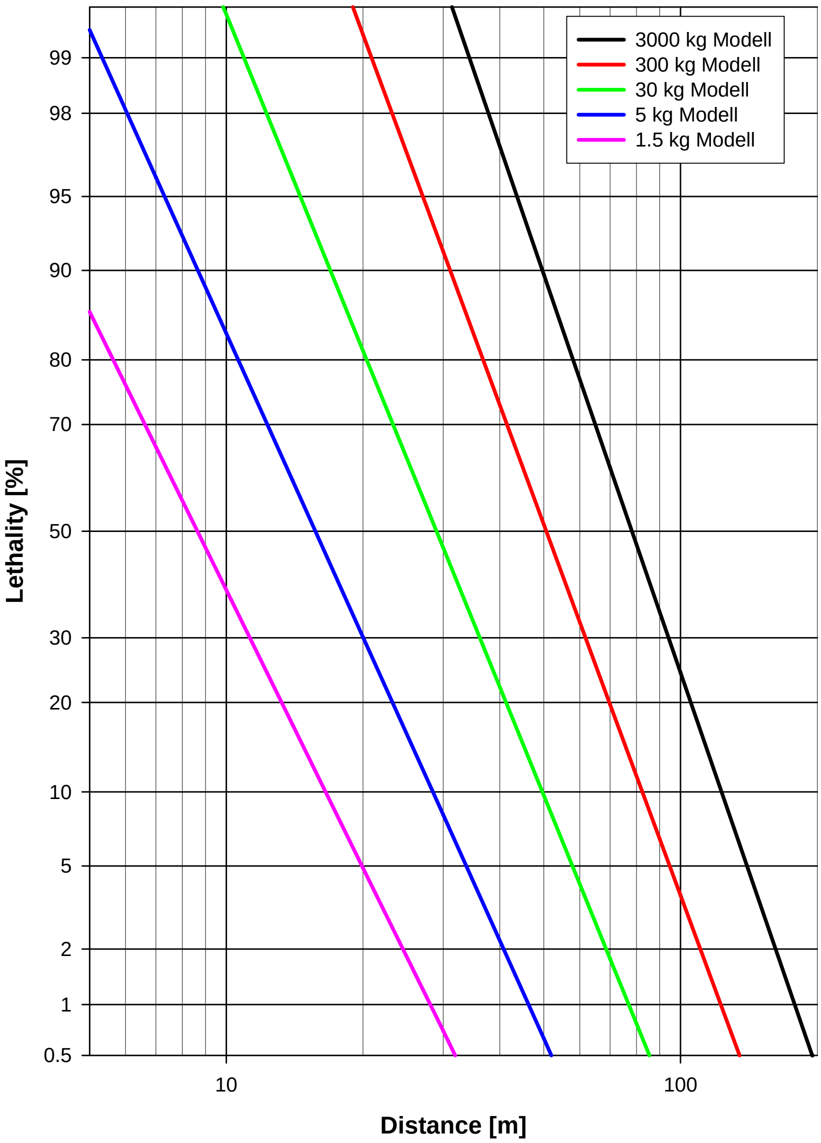

Figure 7: Lethality model for ammunition with "medium" debris potential

Debris Potential	**Function "a"**	**Function "b"**
large	$a = 1 / (0.055 + 0.069 / Q_{TNT}^{0.5})$	$b = -2.869 + 0.896 \cdot e^{(-QTNT / 25.99)}$
medium	$a = (74.16 + 28.11 \cdot \ln (Q_{TNT}))^{0.5}$	$b = -3.568 + 1.663 \cdot Q_{TNT}^{-0.1}$
small	$a = 1 / (0.083 + 0.041 / Q_{TNT}^{0.5})$	$b = -2.149 + 0.175 / Q_{TNT}$

Table 8: Formulae for the Parameters a und b as a function of explosives weight (Q_{TNT}) in kg

5.2 Final Remarks

This model for the calculation of the lethalities due to non-massreacting ammunition debris throw from an explosion on a vehicle adds a new and important tool to the arsenal of the TAE risk analyst. Ammunition debris throw clearly is a relevant explosion effect for free-field exposition, and presumably for exposition in buildings as well.

Even though the model was developed with financial and time restraints, it is adequate and has normative character for Swiss TAE risk analyses.

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8 Lethality of Persons due to Debris Throw – Update on Recent Work in Switzerland

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Kummer, Peter
DDESB 2010 / 15.07.2010

DDESB Seminar / July 2010
Portland / OR / USA

Lethality-Model for HD 1.2/1.4 Ammunition Debris Throw due to an Explosion on a Vehicle

1. *Introduction*
2. *Data from Literature*
3. *Number of Debris Pieces*
4. *Distribution of Debris Pieces*
5. *Lethality Model*

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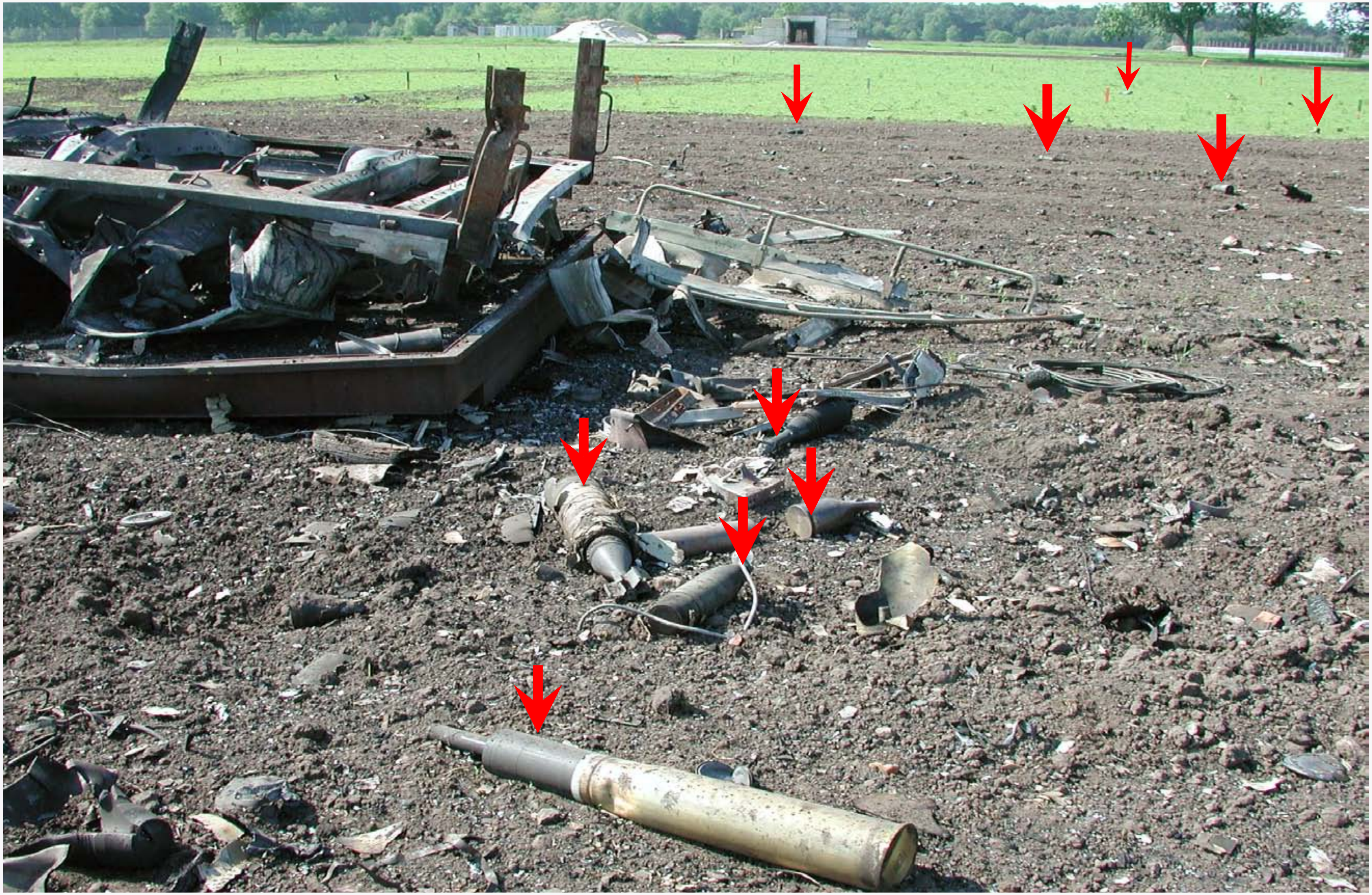
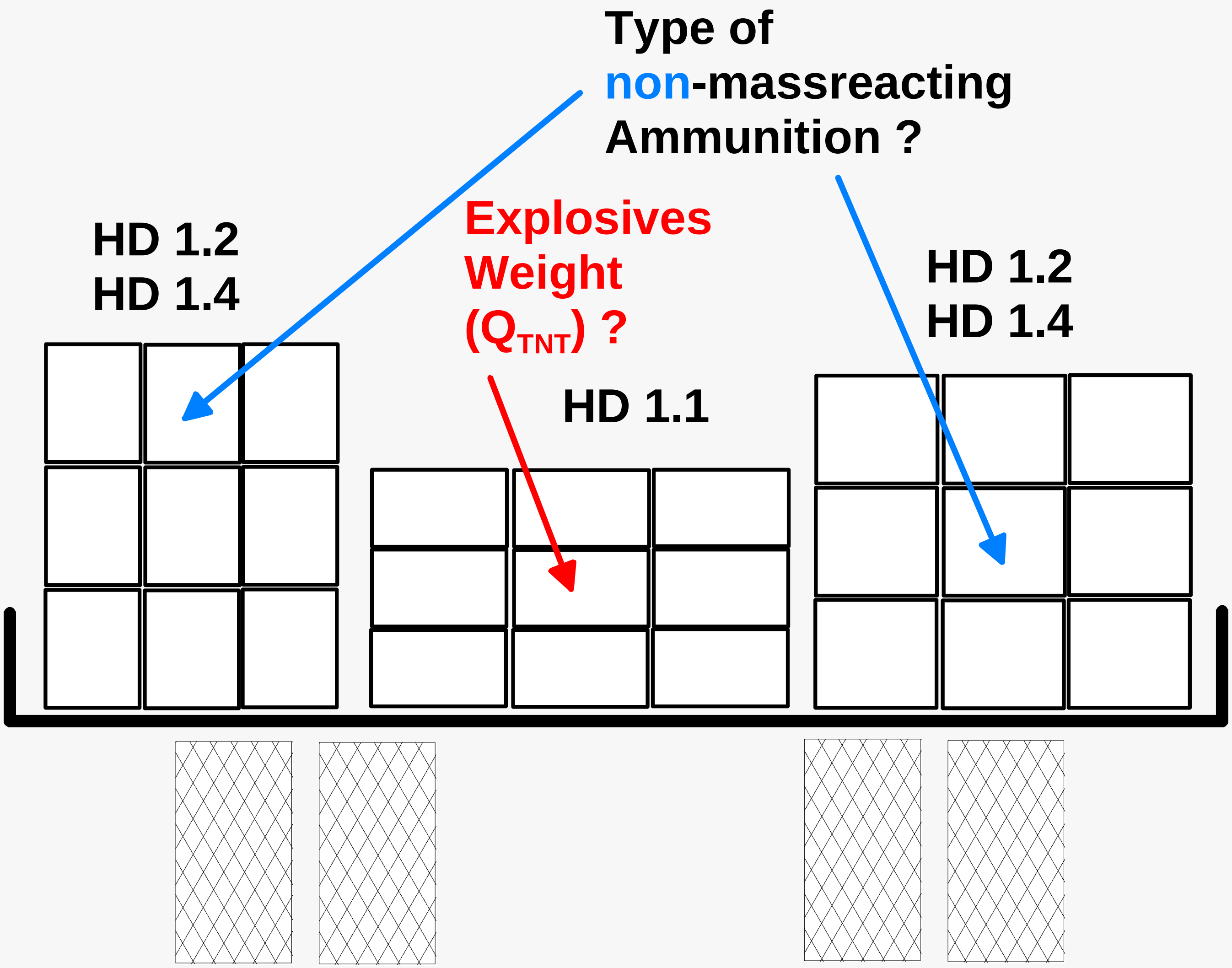
Introduction (1)



German Test with Tank Ammunition on Truck on Fire

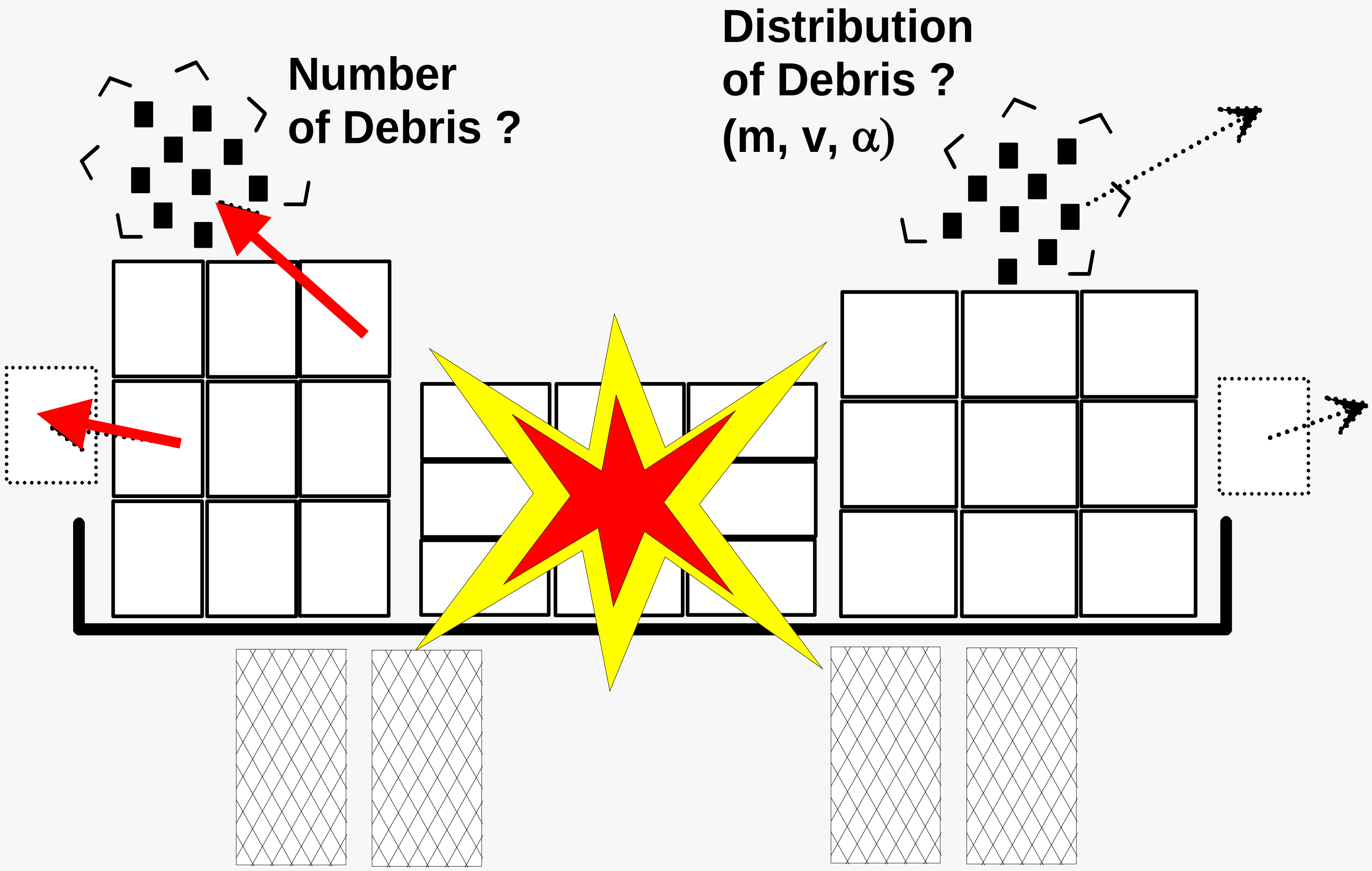
Introduction (2)

Typical Load Configuration



Introduction (3)

What’s the Problem?



Introduction (4)

No applicable model, only scarce data

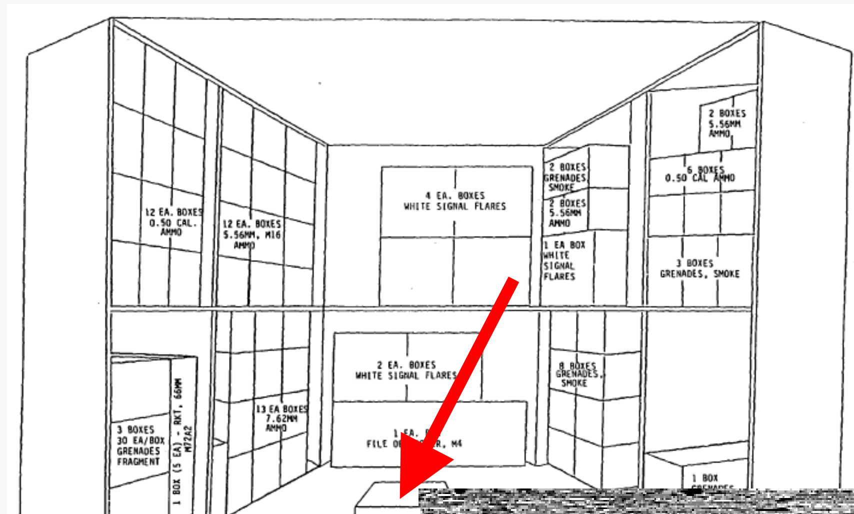
→ Engineering Approach:

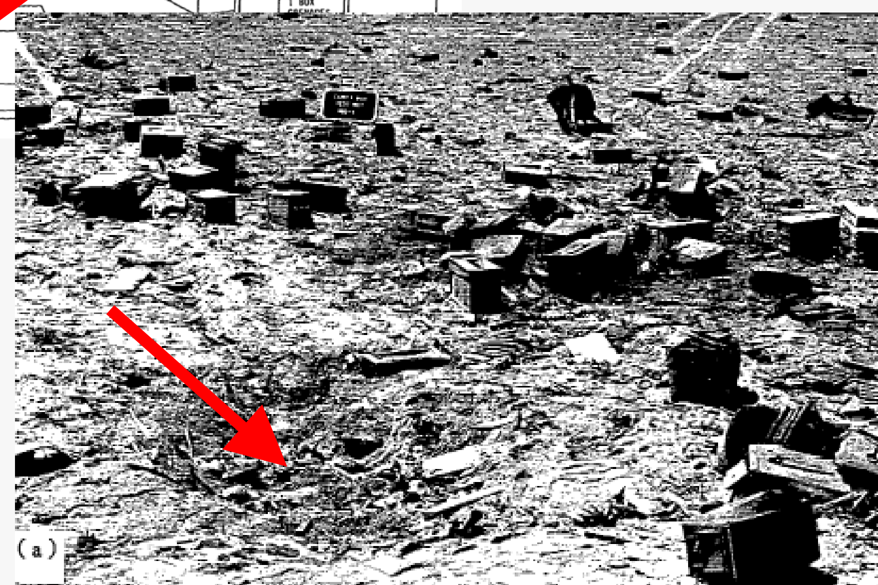
1. **Estimate the number and type of debris pieces generated**
2. **Distribution of these ejected debris pieces in the surroundings**
3. **Calculation of the lethalities due to debris throw**

Adequate model for transportation of ammunition and explosives (TAE)

Data from Literature (1)

US-Tests with CONEX-Containers





Data from Literature (2)

US-Cookoff-Tests with HD 1.2 Ammunition

- **Test no. 9 almost mass-reacting (81 mm Grenades)**

Others:

- **GE-Cookoff-Test with Tank Ammunition on Truck**
- **NO-Accident with Medium-Calibre Ammunition on Truck**

Number of Debris Pieces (1)

General Influences

1. **Explosives Weight (Q_{TNT})**
   - Large Q → more destruction → more debris pieces
   - But: Load limited on truck, (very) small debris pieces not lethal

2. **Type of Ammunition Debris**
   a) From HD 1.1 boxes (not primary fragments)
   b) From HD 1.2/4 boxes and their contents (close-in)
   c) Whole HD 1.2/4 boxes of ammunition (further away)

3. **Configuration of Load on Truck**
   - Simplified

Number of Debris Pieces (2)

Groups of HD 1.2 or 1.4 Ammunition Studied

Ammo-Group	Calibre	Example
1: Small calibre	< 10 mm	Rifle
2: Medium calibre	10 - 50 mm	Airplane cannon
3: Large calibre (Lcal)	> 50 mm	Artillery
4: Lcal + propellant	> 50 mm	Mortar
5: Small grenades	-	Hand grenade
6: Rockets / Tank	-	Tank ammo

Number of Debris Pieces (3)

Matrix for the Calculation of the Number of Debris Pieces at the Source

Basis-Input-Param	Number of 1.2-Ammo-Palets		Number of Donor Debris		Ratio of Debris Type for 1.2-Ammunition	
	close	3	per Box with Q_{TNT}<15kg	17	Single Debris (Parts of Ammo or Box)	30%
	farther away	4	per Box with Q_{TNT}>15kg	33	Box Debris (whole Boxes)	70%

Q_{TNT} [kg]	Type of Palet	Radius of Destruction	Small calibre Kkal Single D.	Small calibre Kkal Box Debris	Medium calibre Mkal Single D.	Medium calibre Mkal Box Debris	Gkal with propellant Single D.	Gkal with propellant Box Debris	Gkal Single D.	Small Grenades Single D.	Small Grenades Box Debris	Rockets / Tank Ammo Single D.	Rockets / Tank Ammo Box Debris	Remarks	
1.5	Donor	1 Box	17	17	17	17	17	17	17	17	17	17	17		
	surrounding	small	4	0	10	0	4	0	0	11	0	4	0		
	Total	-	18		20		18		17	20		18			
5.0	Donor	1 Box	17	17	17	17	17	17	17	17	17	17	17		
	surrounding	small-medium	375	15	1008	4	405	9	7	1125	15	360	9		
	Total	-	140		322		144		24	365		131			
30	Donor	1 Box	33	33	33	33	33	33	33	33	33	33	33		
	surrounding	medium	1688	68	4536	16	1823	41	32	5063	68	1620	41		
	Total	-	587		1405		608		66	1599		548			
300	Donor	10 Boxes	72	72	72	72	72	72	72	72	72	72	72		
	surrounding	medium-large	2813	113	7560	27	3038	68	54	8438	113	2700	68		
	farther away	small-medium	500	20	1344	5	540	12	10	1500	20	480	12		
	Total	-	1158		2765		1201		135	3146		1081			
3000	Donor	100 Boxes	154	154	154	154	154	154	154	154	154	154	154		
	surrounding	large	3750	150	10080	36	4050	90	72	11250	150	3600	90		
	farther (only rail)	medium-large	3750	150	10080	36	4050	90	72	11250	150	3600	90		
	Total	-	2614		6253		2710		298	7114		2440		**Remarks**	
		Box/Pal.	*50*	*50*	*12*	*12*	*30*	*30*	*-*	*50*	*50*	*10*	*10*	*average per group*	
	Number of Debris	*Debris/Box*	*25*	*1*	*100*	*1*	*40*	*1*	*-*	*25*	*1*	*100*	*3*	*for Q $_{TNT}$=3000 kg*	
	as Function of	*Total Box*	*1250*	*50*	*1200*	*12*	*1200*	*30*	*-*	*1250*	*50*	*1000*	*30*	*per Palet*	
	Ammo Group	*Ammo/Pal.*	*40000*	*-*	*1080*	*-*	*75*	*-*	*24*	*2500*	*-*	*10*	*-*	*average per group*	
	for large Q $_{TNT}$	*Debris/Ammo*	*0*	*-*	*2*	*-*	*2*	*-*	*1*	*1*	*-*	*20*	*-*	*for Q $_{TNT}$=3000 kg*	
		Total Ammo	*0*	*-*	*2160*	*-*	*150*	*-*	*24*	*2500*	*-*	*200*	*-*	*per Palett*	
		large	***1250***	***50***	***3360***	***12***	***1350***	***30***	***24***	***3750***	***50***	***1200***	***30***	***Total Box+Ammo***	
	Destruction of	*medium-large*	*938*	*38*	*2520*	*9*	*1013*	*23*	*18*	*2813*	*38*	*900*	*23*	***0.75***	***Red.Factor***
	1.2-Ammo Pal.	*medium*	*563*	*23*	*1512*	*5*	*608*	*14*	*11*	*1688*	*23*	*540*	*14*	***0.45***	"
	as Function Q $_{TNT}$	*small-medium*	*125*	*5*	*336*	*1*	*135*	*3*	*2*	*375*	*5*	*120*	*3*	***0.10***	"
		small	*1*	*0*	*3*	*0*	*1*	*0*	*0*	*4*	*0*	*1*	*0*	***0.001***	"

Distribution of Debris Pieces (1)

Maximum Range

Test	Q_{TNT} [kg]	R_{max} [m]	Ammo-group/ Debris-type	Donor M / N	Remarks
CONEX 1-3	10	115	1 + 5	M-Donor, separated	In Container
CONEX 10	227	335	Whole Box	M-Donor, separated	In Container
Cook-off N	1.5	350	Other Debris	N-Donor, in N-Ammo	Average Q
Cook-off N	1.5	300	4	N-Donor, in N-Ammo	Average Q
German Test	1.5	310	NA	N-Donor, in N-Ammo	Possibly Fragments
Cook-off M	15	460	4, other	N-Donor, in N-Ammo	Test 9

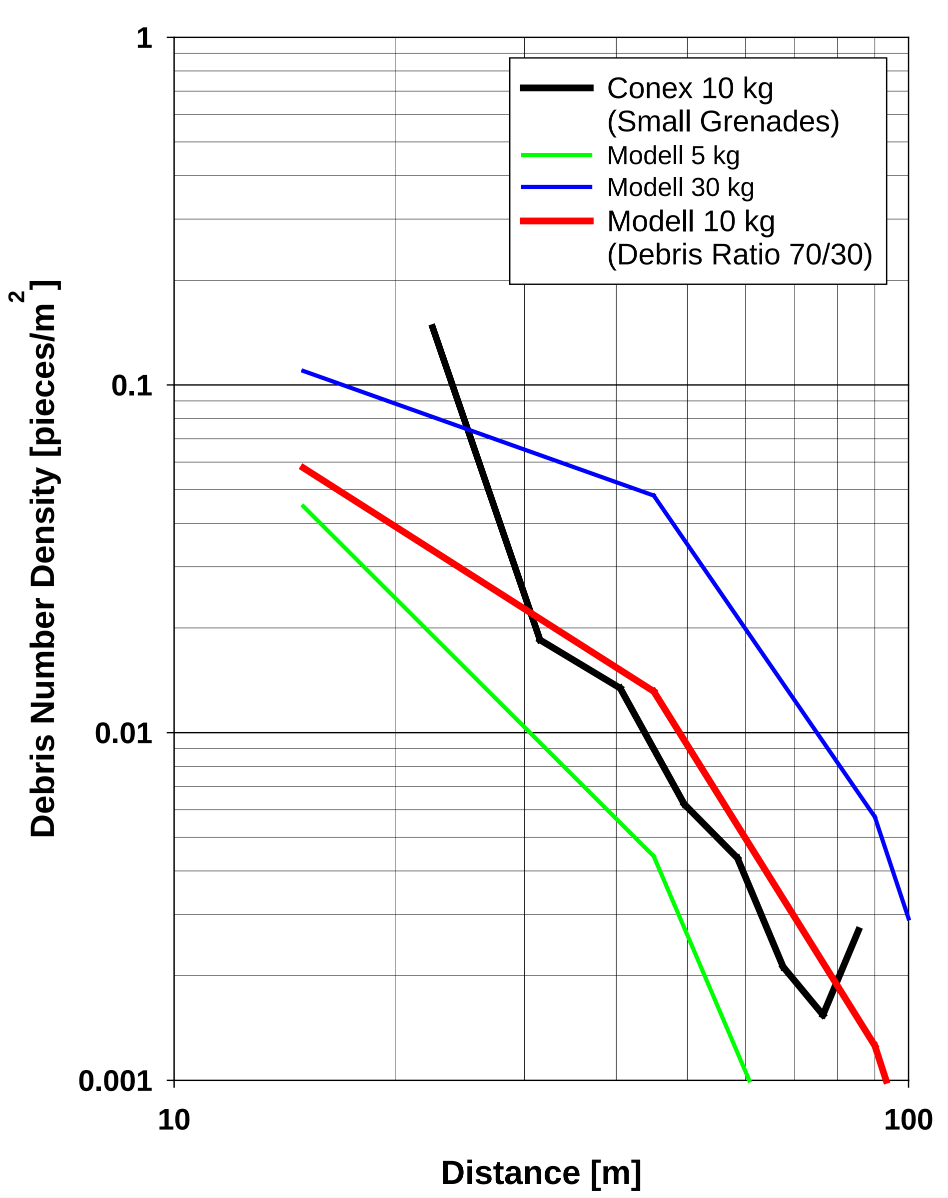
Simulations with TRAJ shows that small arms ammunition debris only lethal in close range

Distribution of Debris Pieces (2)

Resulting Debris Distribution / Density

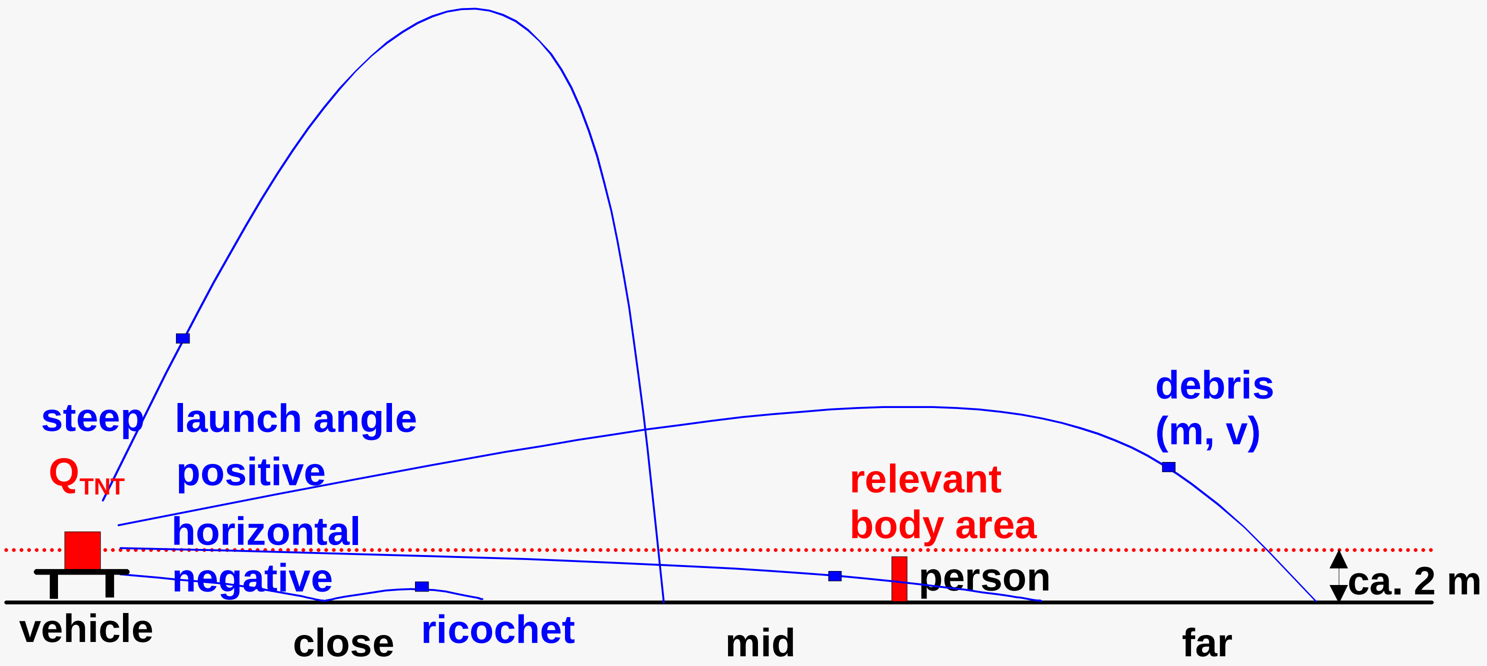
and Comparison with CONEX Data

→Circular debris distribution assumed



Lethality Model (1)

Lethality due to Debris Pieces



- NATO's 79 J lethaltiy criterion

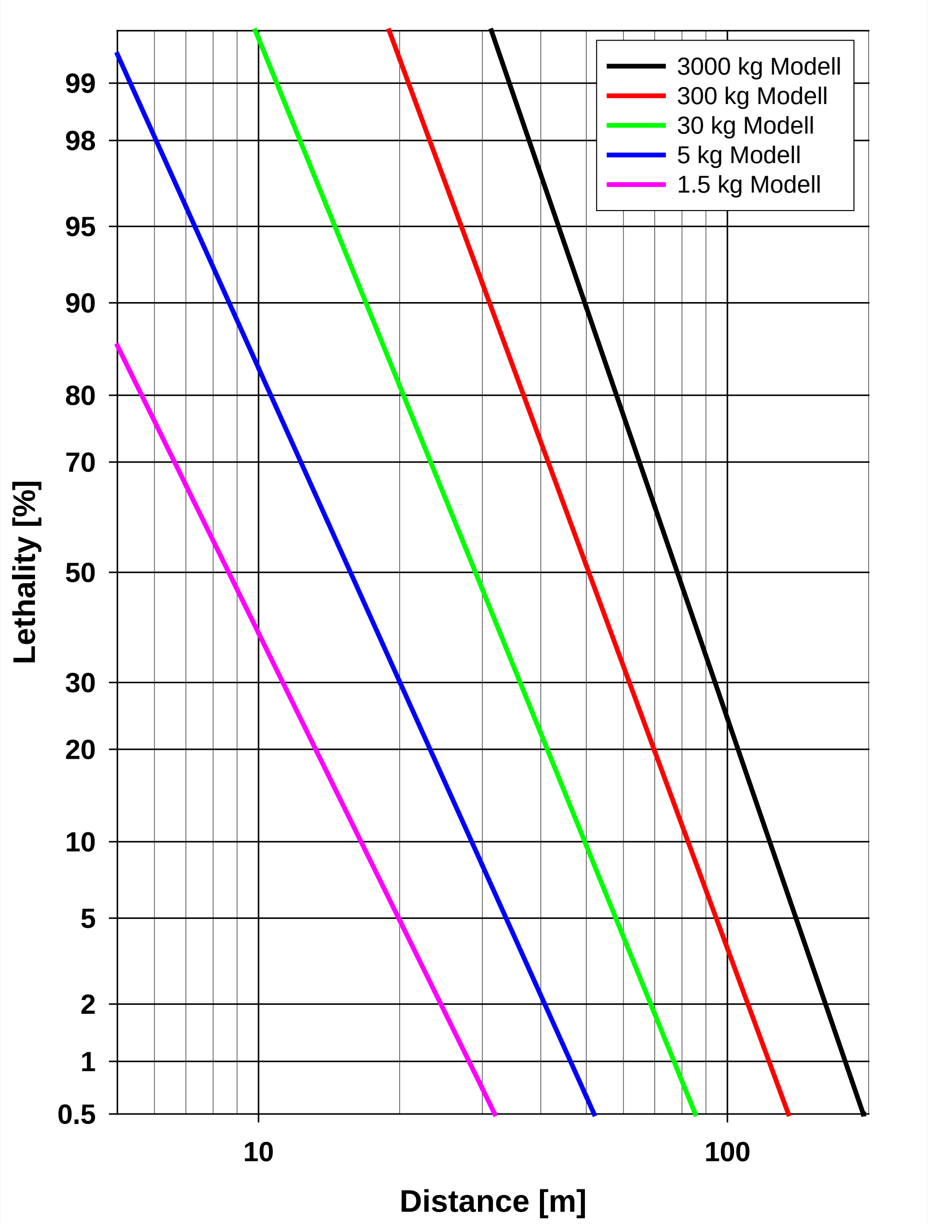
- Relevant body area of 0.4 m²

Lethality Model (2)

Lethality as Function of Explosives Weight (Q_{TNT}) and Distance

For “medium” debris potential

Ammo-Group (HD 1.2, 1.4)	Debris Throw Potential		
	large	medium	small
1: Small calibre		X	
2: Medium calibre	X		
3: Large calibre (Lcal)			X
4: Lcal + propellant		X	
5: Small grenades	X		
6: Rockets / Tank		X	



Lethality Model (3)

Comparison with other explosion effects models, e.g. air blast

→ **Conclusion:**

Adequate model for lethalities due to debris throw from non-massreacting ammunition debris

Model is relevant for certain mixed load configurations of TAE